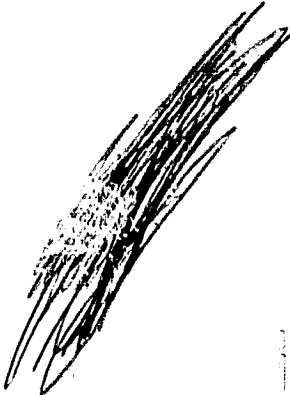


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ENGINEERING-ECONOMIC SYSTEMS DEPARTMENT

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STANFORD, CALIFORNIA 94305

**THE ECONOMIC BASIS FOR NATIONAL
SCIENCE AND TECHNOLOGY POLICY**

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Abstract

National science and technology policy is concerned with societal choices with respect to the rate and directions of technological change and the adoption and use of new technology in society. Such policy choices occur primarily in connection with management of the creation, dissemination, and use of scientific and technical information. Two categories of policy instruments are discussed: (1) market-oriented approaches; and (2) direct public action. This paper is primarily concerned with pointing out possibilities for increased use of market-oriented approaches that can provide benefits to society in the form of an increased rate of innovation and of more "appropriate" technology, better suited to the needs of consumers.

1.0 INTRODUCTION

National science and technology policy is concerned with societal choices with respect to technological change and the adoption and use of new technology in society. The creation of new technology can be viewed as the creation of new knowledge or information through research and invention. Invention and research, in turn, draw on previous work, and a society's policies with respect to the storage, retrieval, and dissemination of scientific and technical information are important elements of national science and technology policy. The adoption and use of new technology in society can be influenced in many ways by government policies and actions that deal with questions of access to or the provision of information concerning the new technology to users. This paper is concerned with all three stages of the information production-consumption process in the science and technology field: creation, dissemination, and use.

A government agency, such as NASA, is involved with all three stages of the information production and consumption process in its own field of space science and technology. It creates new information through its research and development programs. It disseminates this information and assists nonaerospace firms and various government agencies in making use of this information through its technology transfer program. And NASA is also, of course, a user of both NASA-created and other information in its own research and development programs. A private sector firm is also typically involved in all stages of this process in its own field of activity.

The objectives of national science and technology policy have traditionally been thought of in terms of increasing economic efficiency, productivity, and GNP. These overall national economic objectives can each be affected by changes in policy with respect to creation, dissemination, and use of scientific and technological information, and a number of these connections will be discussed here.

Efficiency, productivity, and GNP are all quantities that are independent of what is being produced. By focusing on these economic measures it is implicitly assumed that the national output is produced in properly functioning markets, in which the goods and services that are preferred by consumers are being provided. Of course, only a portion of the national output is produced in properly functioning markets in the U.S. or any other country. If only a small fraction of the GNP is produced outside of properly functioning markets, the effects of ignoring the nonmarket sectors in developing science and technology policy may not be serious. However, the U.S. economy has become a non-market economy in many of its major sectors, and it is doubtful if these sectors can be ignored in future planning. Several types of deviations from a free market exist, and some of their implications for science and technology policy will be discussed. Those deviations of special interest here are: (1) monopoly; (2) government regulation; (3) government provision of services; and (4) the fact that the principal costs of provision of services are being incurred by users rather than providers. As a result of these deviations from a free market, the validity of focusing primarily on productivity and GNP when seeking to formulate national science and technology policy becomes doubtful. An

attempt is made here to suggest some more relevant measures of economic performance, but these suggestions can only be viewed as preliminary at this stage.

The growth rate of productivity has been decreasing in the 1970's in the U.S., while this quantity, along with the real GNP, has continued to increase in Japan, West Germany, and some other nations [1]. Economic (GNP) growth in the U.S. has been primarily a result of an increase in productivity and only in small measure a result of capital investment [2], [3]. The factors that influence productivity are therefore of considerable interest. The entire subject is confused by the use of noncomparable measures and by the aggregation of sectors of the economy, such as manufacturing and services, that may have widely different rates of change of productivity. However, in the period 1900-1960 steady productivity increases in both manufacturing and agriculture occurred. Denison has put forward the hypothesis that, since schooling increased in the U.S. during these years of productivity increase, schooling was responsible for the increase [4]. A more persuasive argument put forward by Klein is that productivity increased as a result of innovation in dynamically changing competitive U.S. markets [5]. Klein's argument is that the U.S. market is now less competitive and that, since firms feel less pressure to innovate, there is less innovation and consequently a reduced rate of increase in productivity. Causes of the decline in competitive markets can be found in the increased roles in the economy of industries subject to regulation, industries with highly concentrated market structures, and governmental provision of services.

In addition, it has been widely observed that the U.S. is now an "information economy," in the sense that more than half of our paid workers and our economy is now engaged in the production of information-related products or services [6], [7], [8]. Information is not like other economic goods, because new ideas can be copied, usually at a much lower cost than the cost of creation. Therefore, the cost of creation of a new idea, through investment in basic research, for example, may not be appropriable, and potential investors will tend to underinvest in basic research for this reason. When we speak of underinvestment in this connection, we mean, relative to the amount of investment that would be socially optimal. Society receives benefits that go beyond the benefits received by the consumers of education and the firms that do basic research. It is therefore in society's interest to intervene in the markets for innovation, information creation, and education through government subsidies or by creating incentives for enhanced investment in these activities in the private sector. Various governmental actions have been taken to make investment in innovation more attractive, including patent, copyright, and tax incentives. Direct public support of basic research and education is also a traditional part of national science and technology policy. It is not at all clear that reliance on these traditional policies will be the most effective national policy in the years to come.

Perhaps the most significant deviation from a market economy in the U.S. is a result of the existence of the "household economy" in which the final output of the market economy is combined with user

time to produce the services that users ultimately consume [9], [10]. The existence of the household economy is not a form of market failure, but its existence raises a question, familiar in system analysis, of possible suboptimization through a focus on the market economy portion of the total system, rather than on the total system which includes both the market economy and the household economy. If the household economy were small in comparison with the market economy, a policy focus on the market economy might be justified. However, in the U.S., the household economy is comparable to the size of the market economy [9]. Therefore, it may turn out to be very important to consider the effects of science and technology policy on the household economy along with its effects on the market economy.

2.0 THE PRODUCTION AND CONSUMPTION OF SCIENTIFIC AND TECHNOLOGICAL INFORMATION

The information production-consumption process can be thought of as beginning with the creation of new information and proceeding through a dissemination process to the user who then consumes the information or uses it, possibly in creating a further innovation. An innovation that is brought to the market often includes both a new technology and a new concept of how this new technology can be utilized. Innovations often create new information that is disseminated and incorporated in other new products or services, etc.

There are three main policy instruments that have been used to encourage individuals and firms to create, disseminate, and utilize new information: (1) patents and copyrights; (2) direct funding of

research, development, and production by the government; and (3) subsidizing and other facilitating private sector investment in innovation and related activities. These policy instruments will be discussed in the following.

2.1 Patents and Copyrights

When we think of the individual inventor or creator of a new work of art, it is easy to see the economic effects of granting a patent or copyright to this individual. The patented invention or copyrighted work is protected against copying for some period of years and is thus made more valuable and more readily sold, and this increased value creates an incentive for further investing in innovation and invention.

There is an apparent tension between the policy objectives of obtaining a high national level of creativity and the policy objective of obtaining rapid dissemination of the results of the creative process. The policy instruments, such as copyright laws, that have been used to encourage creativity do so by creating barriers to copying and apparently act as obstacles to rapid dissemination. However, the tension is primarily a tension between short and long run objectives. In the short run, an innovation can perhaps be most rapidly disseminated by allowing free access to it. But in the long run, it is necessary to be concerned not only with dissemination of known ideas, but also with the continued creation of new ideas, so there will be something to disseminate. Patents and copyrights encourage both innovation and the disclosure of innovation. The alternative of

allowing free dissemination results in innovations being kept secret as far as possible, which obviously does not promote dissemination. Even under a property right system, many innovations, such as computer software, are not protected, and innovators often go to considerable lengths to keep their ideas secret [11], [12].

The effects of patent laws on the operation of a modern, competitive industrial market can be rather different from the effects on individual inventors. In modern industry, the invention process has been commercialized. Inventors are hired and organized to create new ideas that will be most beneficial to the firms that employ them. In some markets the innovation process has been accelerated to a very high pace. The computer industry is an example of an industry with a rapid development cycle; typically less than 5 years for a major innovation. A rapid obsolescence of products naturally accompanies this rapid introduction of new products. Five-year-old computers may work very well, but their value is only a small fraction of their purchase price.

An important distinction needs to be made between the invention process that may be involved in creating a new product and the innovation process that is concerned with selecting the specific characteristics and technology of the new product and bringing it to the marketplace. Many innovations are not patentable. But innovation is protected by trade secret law and by the time it takes to copy a new product. In a high technology field, the time to copy may be over a year, and a firm that is a year or two behind its competitors may find

that its competitors have written off the costs of creation by the time its product reaches the market, so it does not gain a price advantage through copying. In such a market, copying would not be a successful strategy. The role of patents in such a market is unclear. Patents on basic inventions that will be used in several cycles of innovation have long-term value. Patents on obsolete products are obviously not of value. The usual argument that firms will underinvest in innovation does not seem to apply to rapidly changing, high technology markets. Firms in these markets must innovate in order to survive. Firms can effectively nullify the effects of patents by entering into cross-licensing agreements. Firms, in effect, give up the potential rewards from occasional basic patents in order to avoid the risk of competitors' inventions blocking their access to the market. Of course, cross-licensing and patent pools can violate the antitrust laws [13]. But if all new entrants to an industry can join the licensing agreements, the effects are not anticompetitive.

The economics of invention and innovation in markets with rapidly changing technology appears to be an important field for research [14]. Neither the operation of such markets without government intervention nor the effects of patents and cross-licensing agreements in such markets are now well understood.

2.2 Direct Funding of the Creation of New Information

As an alternative to creating property rights in new information through patents and copyrights, direct public investment can be made

in the creation of new information. In areas in which the government has a mission responsibility, as in defense and space, it can be expected to support the research that it believes will be most beneficial to its missions in the long run. In areas in which the private sector is responsible for providing products and services to consumers, there is also a potential role for government supported research, especially basic research. The economic argument that firms will underinvest in research that leads to inventions subject to copying is even more applicable to basic research that is aimed at understanding nature, because patents do not cover theories or laws of nature. Thus, the discoveries that come from basic research will benefit a firm's competitors as much as the firm itself (except for public relations benefits), so the amount of basic research done in the private sector will tend to be less than is socially optimal [15], [16]. Some form of governmental intervention in the market, in order to create increased incentives for carrying out basic research, is therefore appropriate. And direct government funding is a straightforward way to support basic research.

Once government funding of research is adopted as a national policy, a question arises with respect to the ownership of patents and copyrights on innovations made in this research. Presumably, the national interest is best served by a government patent policy that will maximize innovation. Government ownership of patents results in disclosure, but it does not create incentives for firms to make the necessary investments to bring these patented innovations to the market. Granting of exclusive rights to firms that do make such

investments would enhance the incentives to develop these innovations, much as homestead rights have been used to encourage the development of government land.

Another important policy issue in this area is that of the allocation of funds. What areas of research should receive funding, and at what levels? A balance of many diverse interests is somehow achieved in the present system. However, there may be opportunities for improving the present system, for example, by creating more independent sources of research funding that are likely to support research leading in new directions. Both industry and mission-oriented agencies could strengthen their positions in the long term by supporting basic research projects of special interest to them, rather than relying on others to provide this support.

2.3 Facilitating Private Sector Investment in the Creation of New Information

Industrial investment in research can be increased through tax incentives. However, there is the risk that the amount of new research may be small in relation to the amount of tax subsidy, because firms have an incentive to reclassify existing activities to qualify for favorable tax treatment as well as to initiate new research.

Also of importance is the possibility of more industry-sponsored research, on an industry-wide basis, in universities, industrial research labs, or research institutes. There are likely to be many cases arising in the future in which it is important for an entire industry to develop a new set of techniques that will be used throughout the industry. Projects to develop these techniques could appro-

priately be funded and managed by the concerned industries themselves, without governmental intervention. Industry cooperation in such research programs could, however, have antitrust implications, and it is possible that new legislation would be helpful in encouraging this type of industry-wide research activity.

The principal limitation on industry-wide research is the competitive nature of industrial firms and the desire by each firm for secrecy and the exclusive use of new ideas created by an individual firm. However, there are precedents for this sort of industry cooperation in many industries. The necessary condition for a successful program of this type is a guarantee of access to all outputs of the program to all industrial participants in the program. This condition can best be met by carrying out the research in universities or non-profit institutions, separate to some extent from the firms. It would be difficult to create a successful program that would employ scientists and engineers from the participating firms in the direct conduct of the cooperative research. On the other hand, from a national policy standpoint, a central feature of this approach would be the participation of scientists and design and development engineers from industry in project selection and the directions to be taken in the research done under the program. The incentive for firms to provide this costly participation in the management of the research program would be stronger under an industry-financed program than a tax-supported program.

2.4 Facilitating Private Sector Innovation

The production-use cycle can be entered at the use end rather than the creation end. Policy instruments can be designed to facilitate

the use of existing information in the process of bringing a new product or service to the market, i.e. in the innovation and product planning process. NASA's technology transfer program is designed to assist government agencies and industrial firms in the nonaerospace sectors of the economy in making use of new technology that has been created in the space program and that has promise for utilization in other sectors of the economy.

The policy instruments used by NASA include: (1) creating information "bulletins" or abstracts that describe the new technologies believed to have significant potential in nonaerospace applications and making these abstracts readily available to U.S. industry and government agencies; (2) assisting nonaerospace users in the product planning process, for example by going beyond an informational abstract to a complete business plan for the adaptation of a NASA-developed technology to a specific commercial application. This latter form of technology transfer obviously requires careful project selection, because there may be hundreds of possible products or services that could be developed from a specific NASA technology. However, it has the important value that it creates an example that is specific enough to present potential users with a much more complete picture of the possibilities than a simple description of the technology itself. Even if the sample business plan is not adopted, it could stimulate a user to create a business plan that would be adopted. The technology transfer process is not well understood, but it seems reasonable that it might be economically efficient to go somewhat beyond the basic abstract and document dissemination process.

What is unclear is just how far and in what ways it is efficient for an agency like NASA to enter into the product planning process.

A somewhat different approach to technology transfer is to provide a subsidy to firms willing to undertake product planning and development of products that would use certain classes of technologies or that would provide products or services of certain desired types. Both Japan and England have experimented with this approach, using a "national research and development corporation" as the organizational entity for carrying out this idea. Rep. Fuqua has introduced a bill that would create a U.S. quasi-governmental corporation to encourage the development of new products, processes, and industries using the properties of the space environment [17]. The bill provides for the "space industrialization corporation" to provide funds to industrial ventures under negotiated management plans, with repayment including a profit being required of profitable ventures. This provision follows the plan of British and Japanese corporations that have been organized in the same way with repayment only required from profitable ventures. It also incorporates the important concept of allowing negotiation rather than requiring competitive bids. A sum of \$50 million per year for two years is proposed to get the corporation started. Further funding could be voted. The Fuqua plan creates a corporation that would initially be an agency of the federal government, but provides that it can be converted into a publicly owned private corporation.

A significant advantage of this approach to technology transfer is that it would leave the entire product planning process to industry,

where it can be done best, and it does so in a way that protects the confidentiality of the ideas submitted in proposals. The research and development corporation would not be required to use the competitive bid approach and hence would not have to define the product or otherwise inject itself into the product planning process. It would only have to select which proposals to support. If it maintained confidentiality of the proposals submitted, it could expect to receive proposals with the best available innovative concepts that industry could present. The economic justification for this approach in a market such as the industrialization of space is the uncertainty of profits, combined with very large investment per project required, in a market that would offer long term benefits to the U.S. by maintaining the comparative advantage the U.S. has developed in space technology and applications. There is no reason that this approach could not be used for "market development" programs in a wide variety of fields.

3.0 IMPROVING THE OPERATION OF MARKETS IN ORDER TO ENCOURAGE INNOVATION THAT IS RESPONSIVE TO CONSUMER DEMAND

It has become apparent in recent years that industries with a high degree of concentration, with strong local monopolies, or with high barriers to entry more often than not achieve their protection from competition through government action [18]. Industries that consist of a few large firms seem to have less incentive to innovate, if it is difficult for small competitors to enter their market with innovative new products. In industries where small competitors can enter the

market rather easily, as in the computer industry, small firms provide a very large fraction of the innovation that occurs.

Four major types of policy options are considered here that are of interest in dealing with industries that have somehow managed to obtain governmental protection from competition: (1) deregulation in "regulated industries" such as railroads; (2) deregulation in "unregulated" markets; (3) improved consumer information in all markets, but especially in local service markets; and (4) privatization of markets dominated by government providers of service.

3.1 Deregulation of "regulated industries"

Although government regulation is often adopted as a consumer protection measure, the eventual effect is usually to limit competition by creating barriers to entry to the regulated market [19]. The pace of technological change in regulated markets is slowed for a number of reasons. Governmental approval may be required to make new investments of certain types, and the regulatory process can be used to prevent an innovative firm in a regulated market from introducing new technology as fast as it would like. Once new technology is in place, the regulatory process can be used to prevent pricing services that use the technology in ways that would threaten less innovative service providers. In addition, regulators and regulated industries may adopt pricing strategies that minimize present prices but slow the introduction of new technology that would reduce prices in the future. Only in markets where competition is restrained by government action can these anti-innovation policies be pursued and sustained for long periods of time.

A government can, thus, through its own actions, create a competitive disadvantage for its industries in world markets. Of course, governments do not act to regulate an industry without the consent of the industry, and usually governments are pushed into regulation by industry, in order to limit competition [20]. However, when new national policies to encourage innovation are being considered, it is difficult to think of a more significant policy option than deregulation, in industries presently subject to regulation [21].

This argument does not depend on economic studies of innovation as a function of firm size or market structure. A number of studies have been made of the various economic characteristics of firms, in an attempt to identify market conditions favorable to innovation. It has been suggested that large firms may be more apt to innovate than small firms, because they have more flexible resources [22]. Firms in competitive markets that are not too fragmented have been found to be more innovative than firms in either highly concentrated markets or markets with a large number of very small firms [23]. However, the rate of innovation is also strongly a function of the specific industry and its stage of evolution [24]. Regulation could be used to influence firm size or market structure, but its direct effects on innovation are, in the author's opinion, much stronger than any of the other market characteristics that have been studied. And the evidence is that regulation is consistently used to slow the pace of innovation. For example, the rate of innovation in the business telephone terminal market was extremely slow when this market was protected from competition. The Carterfone decision in 1968 opened this market to competition, and

there has been a high rate of innovation since that date, both by AT&T and its new competitors [25], [26]. The opportunity exists to increase innovation through deregulation in many other U.S. industries.

Deregulation would not only tend to benefit consumers through an increase in the availability of new products and services, but also through reduced prices for existing services resulting from process innovation. Perhaps equally important in the long term would be the improved position of the U.S. in world markets in the deregulated industries. In many cases regulated industries in the U.S. are industries that are completely governmentally managed in other countries, such as railroads, telephones, and broadcasting. Thus, even though technological change in these industries has been limited by regulation in the U.S., it has also been slowed in other countries by even more constraining governmental action. Therefore, the U.S. is not yet at a competitive disadvantage in most of these areas. And the opportunity to take or maintain the lead in these areas is still open.

As these markets are deregulated and start to admit innovation at an increased rate, foreign equipment suppliers will be attracted to these markets along with U.S. suppliers. Pressures will then undoubtedly develop to protect U.S. equipment suppliers from foreign competition. Protectionism in these markets will be more easily justified, if foreign markets of the same types are not open to U.S. industry, as is almost certainly going to be the case initially. In the long term, however, international competition may cause deregulation worldwide, if it is initiated by the U.S. and if deregulation does lead to more rapid technological change. A more rapid rate of technological change in the

U.S. and an improvement in the relative position of U.S. firms in these industries relative to foreign firms may create pressure for deregulation worldwide as a competitive response.

The trend toward more rapid diffusion of innovation throughout unregulated world markets has been widely noted. Lower wage costs in developing countries make them competitive sources of manufactured goods, thus putting more pressure on the developed countries to increase the pace of innovation. At the same time, the growing world markets are making it easier to write off R&D expenses and to finance innovation. The deregulation of U.S. regulated markets would simply be another step in this process.

3.2 Deregulation in "unregulated" markets

Many industries that are not regulated in the sense that public utilities are regulated are nevertheless neither competitive nor innovative. Usually these industries are highly concentrated and the role of government in these industries is often anticompetitive, even though less obviously so than in the case of public utilities.

For example, in the drug industry the government plays a complex role. In connection with prescription drugs, advertising of prices and the introduction of generic drugs would obviously increase competition. The high cost of testing new drugs creates a barrier to entry by new smaller firms. Government policies aimed at increasing competition could encourage innovation in this industry.

The broadcasting industry plays a key role in the economy. It is not regulated in the way that public utilities are regulated. A market

in broadcast stations exists; entry is possible through purchase of an existing station. But government plays a central role in limiting competition and the operation of the market in this industry [20]. For example, pay-by-program television has been technically feasible since the late 1950's. But the introduction of pay television into the broadcast market would create economic risks for the existing networks and stations. Their markets have been protected from pay television competition up to the present time by restrictive FCC rules and the administration of those rules, even though it makes no more economic sense to ban pay television than it would to prevent magazines from charging consumers for copies and allow only magazines that relied exclusively on advertising for their revenues to exist.

There are many opportunities to increase competition and innovation in unregulated U.S. industries, simply by withdrawing governmental support for anticompetitive practices in these industries. Thus, the science and technology policy option of greatest significance in many industries today is simply the option of repealing previous legislation. This statement has many detailed implications that differ from industry to industry. And each industry would require a major study and analysis effort, as well as a political consensus sufficient to overcome industry opposition to deregulation, in order to implement a deregulation policy option. That such an option is worth considering has been demonstrated by airline deregulation.

3.3 Consumer Information

A well functioning market requires that consumers have adequate information about price and quality. Otherwise, competition cannot exist. Yet, in many consumer markets, the consumer not only has inadequate knowledge of product quality, but also has difficulty obtaining even price information. Most advertising is not intended to provide this type of information, but rather to inform consumers of the existence of products, sources of services and products, and to create favorable impressions of the advertised product or service. While Consumers Union provides comparative information of the type that consumers need on nationally advertised products, very little information is available on the local services and products that consume most of the consumer's income: housing, medical services, auto repair service, and other local services.

It is not reasonable to expect either government or industry to provide the type of information that consumers need. The job will almost certainly have to be done by consumer groups, if it is to be done at all. Nevertheless, the opportunity exists for government to facilitate the development of consumer information services. It is reasonable to expect very substantial gains in the productivity of local services, as well as a much more rapid rate of innovation in these industries, as a result of increased competition that would result from improved consumer information at the local level [27], [28].

3.4 Privatization

In many sectors of the economy the government acts as a monopoly or near-monopoly provider of services. The postal service, the public

schools, public libraries, defense, and the exploration of space are some of the major markets dominated by government or quasi-government providers. One of the sources of difficulty in these markets is the fact that services are provided to users at zero price. Funds are obtained for the provision of these services through general taxation, and these funds are allocated to the service provider by Congress or a state legislature. Such organizations become attuned to the wishes of their legislative constituents, but their incentives to serve their users are weak and exist only to the extent that their users make their demands felt by their representatives in the legislature. In some cases, this system is quite satisfactory. When the users are industrial firms, the likelihood is high that the legislature will adequately represent the interests of the user in dealings with the government service provider. However, when users are individuals, it is difficult for the users to arrange for their interests to be adequately represented. A policy option that is, in principle, easy to adopt is to charge users directly for the service, rather than to use tax funds to pay for the service. The principal benefit of this approach is that service providers become more attentive to their customers. However, this approach does not benefit users to the full extent possible unless users have an alternative supplier to turn to. Thus, the postal service feels some pressure from the threat that users will reduce their purchases of service, but the pressure is much greater, if users can get their packages or messages delivered by an alternative service provider such as United Parcel Service. Thus, the combination of funding through direct user payments with opening

the market to competitors avoids the principal difficulties with government provision of service. But there is still one difficulty with such a market, and that is the fact that both government and private sector monopoly service providers tend not to price their services in proportion to cost. In other words, they subsidize one service from revenues obtained from another service. Such cross-subsidies are often introduced in response to their legislative constituents [29]. Once in existence, such cross-subsidies are politically difficult to eliminate, and their existence can block the adoption of open entry policies that threaten to force the market toward cost-based pricing. An example is the subsidy of rural mail delivery by urban mail. The only satisfactory way of preserving such subsidies is to make them into direct subsidies. However, direct subsidies are more difficult to get political support for; their economic and social effects are often examined more closely than are the effects of indirect subsidies. For example, should rural mail and telephone subsidies be extended to both rich and poor rural dwellers, and, if not, how could the distinction be made on a practical basis?

If a direct subsidy is acceptable politically, as it might be in the case of low income users of public schools and libraries, it can be combined with a direct user payment system by providing vouchers to the low income users [30]. But again, such a system is only fully effective if the user can turn to an alternate source of service if unsatisfied. Once free entry is allowed, along with cost-based pricing and direct user payment, the need for a government service provider often disappears altogether. The only residual trace of

government intervention would then be the provision of vouchers or scholarships to low income individuals. In such a case, full "privatization" of the service can be accomplished.

In defense and space, the path to privatization is not as straightforward as it is in the case of purely domestic services. Nevertheless, in both defense and space in the U.S., the government relies on the private sector for its hardware, software, and some of its operational services, so some elements of privatization are present in these services. The opportunity for further privatization may exist in defense and space, and analysis of this possibility appears to be appropriate. The directions in which innovation in these fields is moving is now determined by a process in which the individual consumer plays almost no role whatsoever. It is not easy to bring the consumer into these fields effectively. A token, uninformed consumer on an advisory board is not an effective mechanism for getting consumer "input." One possibility that has not been adequately explored is the idea of improving consumer-oriented information about the operation and significance of these agencies. Of course, both agencies now spend substantial sums on providing information to consumers, but this information is organized and presented in a way that is likely to strengthen public support for existing programs. The new possibility is to provide information that will cause consumers to question the basic premises and orientation of existing programs and to see some of the options for defense and space that are not now given official support. It is quite possible that a more open, questioning approach to defense and space policy would result in more innovation and more effective programs in the long term.

4.0 IMPROVING THE MANAGEMENT OF GOVERNMENT SPONSORED RESEARCH AND DEVELOPMENT

The market concepts discussed in previous sections have some bearing on the questions of the appropriateness of government sponsorship of R&D and of how project selection in government sponsored R&D should be carried out.

Starting with basic research, there seems to be little controversy over the appropriateness of some form of governmental stimulus to this activity, whether through direct support, patent and copyright protection, or tax incentives. The project selection mechanism is now fairly diverse, and there are many reasons for favoring a diversity-oriented approach to funding and project selection. The economic concept that is relevant here is that the customers or users of basic research should be involved in project selection and funding, by analogy to the role of the consumer in markets. This concept is only occasionally operative today. A possible example of the application of this principle would be to bring product development engineers into the project selection process in the support of research projects in their field at an agency like NSF. This group now influences, to some extent, the paths of basic research within their own companies. It might be feasible to increase their influence in government sponsored programs as well, on the basis that they are the most direct consumers of basic research. The ordinary individual is the ultimate consumer of basic research, and again the only realistic opportunity for increasing consumer participation appears to be through improved consumer information on the basic research establishment and its operation.

Considering next the role of government in relation to applied research and development, the appropriate role is fairly clear in areas in which the government has a mission responsibility and monopoly, such as defense and space. In these areas the government is responsible for funding, project selection, and overall management. The possibility of increasing the degree of privatization and through this, competition and innovation, was discussed above. In civilian markets, there may also be a role for government sponsored applied research and development, but the case is less clear. If there is an appropriate role for government sponsored R&D in civilian markets, it is probably primarily in applied research, because product development is closely tied to the market and is best done by firms that are familiar with the market [31].

Applied research is research that is oriented toward specific applications in specific markets. It is often clear that a specific type of device or technique is of key importance in the evolution of a particular field, and it is clear that the best way to promote progress in this field is through the development of specific devices or examples of the critical technique. In such cases this development is not coupled directly to the market, but rather represents learning work that goes beyond basic research and prepares the way for market-oriented development to follow. An example might be a key component in a large system, such as a new type of communication satellite that would make possible an improved communication system. In such cases, there may well be a case for government sponsorship of R&D on the economic grounds that the private sector tends to underinvest in this

type of work, because it is unable to appropriate the results. A firm is likely to underinvest in applied research that could benefit its competitors as much as itself; it will prefer to wait until there is a specific market opportunity to focus its work on. Thus, if the government can find these critical areas of applied research, it can probably make an important contribution to the national competitive position in whatever industries it chooses to support.

The process by which areas of government applied research are chosen is thus an important element of the R&D program. It may be that there are opportunities for organizational improvements in the project selection process. At the present time, U.S. government agencies have advisory panels that help them to keep in touch with the industry and its views. A possible opportunity for improvement might lie in the way industry representatives are chosen for these panels or in the ways that panel members are able to express their views. In some cases an industry panelist may know of an area that would be productive for government R&D, but may be reluctant to share his ideas with his competitors. There may be an organizational alternative that would allow secrecy to be maintained. For example, if the R&D is government sponsored but done in industry, a negotiated contract rather than a competitive procurement could protect the ideas of the industry R&D group. Of course, this approach would violate many of the existing constraints on government contracting. An alternative to this approach is the creation of tax incentives for R&D, under which firms would make project selections completely on their own [31]. The weakness of this approach is that it results in the

support of a great deal of work that industry defines as R&D for tax purposes, but that may be nothing more than restyling, as in the automobile industry.

One way of looking at government R&D in civilian markets is that the government is acting as an industry-wide cooperative R&D agency. A portion of the industry's corporate income tax can be thought of as being allocated to this purpose, and it is therefore reasonable to expect R&D project selection to be made by industry. In order to avoid the weaknesses of both government sponsored R&D and the tax incentive approach, it might be possible to encourage the development of industry-wide R&D activities outside of government, as discussed in Section 2.3. The "national research and development corporation" concept discussed in Section 2.4 is another option that allows greater confidentiality than a government sponsored program with consequent increased flexibility and potential for innovation.

5.0 INCREASING "APPROPRIATE" INNOVATION IN LARGE-SCALE SYSTEMS

Starting with Jacques Ellul [32], there has been a steady flow of literature concerned with the uncontrolled, apparently autonomous evolution of technology in directions that are "inappropriate" because they are not directions that benefit consumers [33], [34]. The principal contribution of economic theory to this question is to suggest that these "inappropriate" evolutionary trends in technology are most likely to occur in sectors of the economy in which market forces are ineffective, often as a result of governmental action. For example, the choice of new

technology in U.S. hospitals is not limited by considerations of economic efficiency, because insurance payment systems cover all costs and there is no effective competition in this market. The result has been an extraordinary rise in hospital costs [35].

System analysis can contribute to an understanding of these trends by pointing to examples of inappropriate technology in areas in which large-scale societal systems are being built with inadequate coordination and planning, such that "suboptimization" is taking place. The subsystems of these inappropriate systems are being optimized, but no one is looking after the overall system optimization. For example, in attempts to increase productivity in post-secondary education, televised classes have been used to increase the number of students per teacher. Television and other educational technologies such as audio cassettes used in combination with still visuals have been found to have no significant difference from each other and from live classes in their effects on student performance. When optimization of the school's operation through minimization of teaching costs is done, television appears to be the preferred technology. However, if optimization of the entire learning operation, including the cost of student time, is done, technologies such as audio or video cassettes that offer students the chance to listen to lectures when they wish and to review them as often as they wish, result in lower total costs. The optimization of the school's productivity is a suboptimization, because it fails to include the students in the system and the costs of student time that would be included in an overall system optimization. The system boundary in such a case has been incorrectly drawn, from the standpoint of society, even though correctly drawn from the standpoint of the school.

A similar suboptimization is taking place in some areas of national science and technology policy. Present policy focuses on productivity in the market economy and on GNP, the output of the market economy rather than on the output of the total economy. The total economy includes both the market economy and the household economy. In the U.S., the household economy is comparable to the size of the market economy, because for most services that consumers receive, the cost of consumer time is several times as large as the price that users pay into the market economy for goods and services [9], [10]. As in the case of educational technology, there is a danger that firms will choose the best technology from their standpoint and end up with the wrong technology from society's standpoint. Wrong choices by firms will be corrected in markets where users have a chance to obtain services from more than one provider. However, in fields such as education, medical care, defense, and space, where there are local or national monopolies, wrong choices are not automatically corrected.

One approach to science and technology policy that would improve technological choices in large-scale systems is, of course, to improve the operation of markets by increasing competition and consumer choice, as discussed in Section 3. When deregulation and competition are not feasible, it still may be possible to refocus technological choice toward options that will minimize total cost rather than provider cost and that will optimize total system operation rather than the subsystem under the control of the provider. Any new non-market approach to science and technology policy that seeks to induce overall system optimization will probably have to do so by facilitating large-scale system planning that does in fact take users into account in the organizational design.

For example, there are many opportunities for innovation in such areas as city design, in the organizational sense rather than the physical sense. In principle, such local service markets as housing, transportation, education, and policy services could be highly innovative. These markets are presently highly constrained by regulation and most are monopolistic. Both market incentive approaches, such as deregulation and privatization, and new organization designs that encourage overall system optimization could usefully be the subject of analysis and R&D.

6.0 CONCLUSIONS

Science and technology policy is concerned with the rate and directions of technological change in society. Two broad categories of policy instruments are available: (1) market-oriented approaches, such as the modification of property rights in newly created information through patent law, that seek to increase the incentives for the private sector to invest in R&D; (2) direct public action, such as government sponsorship of R&D, that seeks to substitute government action for the operation of the market. Much existing policy makes use of the direct action approach. This paper has been primarily concerned with pointing out possibilities for the use of market-oriented approaches and some of the advantages of such approaches that can be seen from basic economic principles.

The fundamental economic justification for government action to increase innovation in markets is that the private sector will tend to underinvest in R&D because it is not able to fully appropriate the benefits of such investments. The reason for this inappropriability is that the information that results from R&D can be copied by competitors and

the originating firm may, therefore, not be able to recover its costs of creation. In markets that are competitive and in which the industry is at a stage where technology is changing rapidly, investing in R&D is a necessary element for the survival of a producing firm. Innovations in such markets are protected by the fact that it takes a substantial time and effort for competitors to make copies. It is unlikely that firms underinvest in R&D in these markets, and further stimulus to innovation through governmental action is not needed.

In regulated markets and other markets in which barriers to entry are created by governmental action, there is often a variety of administrative obstacles to the introduction of innovation. Deregulation is the most effective mechanism for the stimulation of innovation in these industries.

The objectives of technological innovation for a nation are twofold:

- (1) to maintain or acquire a competitive position in the world market;
- (2) to provide better products and services to the citizens of the nation.

Much of national science and technology policy can be justified by its effectiveness in contributing to the first objective. For example, the use of tax funds in support of education, basic research, and libraries contributes to the development of a national information infrastructure. This infrastructure creates the basis for comparative advantage in international trade in the information-based economies of the modern world. The mechanisms for government action in support of education, basic research, and libraries involve subsidies of these activities. The quality of these activities could probably be improved by giving more control over the character of the services offered to the users rather

than the providers of these services. The organizational approach to providing government support for industrial R&D could also probably be improved. Industry-wide R&D organizations within the government, in government corporations, and in private firms could provide similar services but with different degrees of industry control and confidentiality for innovative ideas.

In many large-scale systems, the evolution of technology has taken place in ways that have been characterized as "autonomous" and "inappropriate," because the technologies seem to have evolved in directions of their own, without regard for human needs. Much of the difficulty can be traced to the fact that these systems are monopolistic; users in these systems do not have an adequate choice. Market-incentive approaches such as deregulation and privatization, offer the most reliable path to the restoration of appropriate innovation. However, in certain areas, such as defense and space, a new approach to science and technology policy that seeks to achieve a more comprehensive approach to system planning may bring innovation that is more appropriate to human needs.

A general conclusion is that there seems to be a number of opportunities for increasing the rate of innovation and for bringing the directions of innovation more closely into line with the needs of users. Most of these opportunities can best be realized by improving the operation of markets by such techniques as deregulation, improving the quality of consumer information, and privatization. A second conclusion is that these improvements could benefit the consumer, both as a member of a nation with a stronger position in the world market and as a consumer of more "appropriate" technology. To obtain these benefits, various forms

of organizational innovation appear to be needed. Studies of new organizational options for the implementation of national science and technology policy would be an essential first step in this innovation process.

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